Hemispheric and Global Air Pollution: Scientific perspectives from the Southern Hemisphere

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Global pre-human background aerosol concentration
300 – 500 cm⁻³

Modeled CCN at 1 % supersaturation,
Spracklen et al., GRL, 2008

Not so much Pristine environment left.
A Global Mean Aerosol Climatology

AERONET / composite Aerosol Optical Thickness (550 nm)

average 0.137

S. Kinne, 2008
a) BC emissions (Tons/yr)

b) BC Atmos Heating (W/m²)

c) Dimming due to ABCs (W/m²)

ABCs: Emission & Global Forcing

BC around 11-17%

Ramanathan and Carmichael, Nature Geoscience 2008
Organic Aerosol Components Worldwide

Poor Southern Hemisphere: is not even in the map…

Global Distribution of Carbon Monoxide (CO) from MOPPIT

1 Mar 2000
Global biomass burning

1997
Land use change was responsible for estimated net emissions of 1.5 PgC per year over the last 15 years. This is 12% of total emissions in 2008, down from 20% in the 1990s.
Forest clearing and forest cover in the humid tropical forest biome, 2000–2005

Forest loss in Brazil accounts for 48% of total biome clearing, nearly four times that of the next highest country, Indonesia, which accounts for 13%.

Hansen M. C. et.al. PNAS 2008
Tropical deforestation drivers
As of 2008, 17% of Amazonia was deforested. By 2050, if current trends continue, about 40% of the forest could be cleared.

Deforestation in Amazonia 1977-2009 in km² per year

What public policies are needed to sustain this reduction?
Fire Emissions from Deforestation Zones

Global Fire Emissions Dataset (vs2)

- America
- Africa
- Asia
- Pan-tropics

van der Werf et al. 2006, Atmospheric Chemistry and Physics, updated
AERONET Aerosol Optical Thickness for 10 sites in Amazonia
Anthropogenic burning was reduced substantially in Brazil in year 2008 compared to previous years including 2007. The OMI/MLS measurements show sizeable decreases 15 – 20% in ozone in Brazil during 2008 compared to 2007 which we attribute to this reduction in biomass burning.
Copenhagen Commitment: Reduction in 80% emissions from deforestation in 2015 from 2004. Same target in the Brazilian law passed in Congress.

Brazilian Greenhouse Gases Emission Inventory 2005

- Deforestation: 56
- Agrobusiness: 24
- Energy + Transport: 12
- Industry: 5
- Landfills: 3

MCT Feb 2010

Copenhagen Commitment: Reduction in 80% emissions from deforestation in 2015 from 2004. Same target in the Brazilian law passed in Congress.
Radiative forcing due to perpetual constant year 2000 emissions grouped by sector

(a) 2020

(b) 2100

Main sectors: Energy, industry and biomass burning

Unger N et al. PNAS 2010;107:3382-3387
Fires and Smoke in West Africa
The Dust and Biomass Burning Experiment, W Africa, suggests that gas phase organic carbon from biomass burning may condense onto the larger surface area of mineral dust (Haywood et al., 2008).
Aerosol plume extending from Himalayas to Indian Ocean
Large scale aerosol distribution:
strong effects on the direct radiation balance and cloud formation

What is the basin wide effect on CO₂ uptake and on VOC emissions?
Biomass Burning in South America
Amazonia
Average aerosol forcing clear sky

Top: - 10 w/m²
Atmosphere: + 28 w/m²
Surface: - 38 w/m²

Conditions: surface: forest vegetation
AOT (τ=0.95 at 500nm); 24 hour average
7 years (93-95, 99-02 dry season Aug-Oct)

INDOEX
average aerosol forcing clear sky

Top: - 7 1 w/m²
Atmosphere: + 16±2 w/m²
Surface: - 23 2 w/m²

Conditions: surface: ocean
AOT (τ=0.3 at 630 nm); 24 hour average
Jan-Mar 99
Aerosol Optical Thickness
550 nm

Solar Radiation
at surface (W m\(^{-2}\))

Continental scale effects
Fire in the Earth System

Current pyrogeography on Earth, illustrated by (A) net primary productivity (NPP, g C m$^{-2}$ year$^{-1}$) from 2001 to 2006, and (B) annual average number of fires observed by satellite

Bowman et al., Science, 2009
Global Deforestation Fires: Responsible for 19% of global radiative forcing

Estimated contribution of fire associated with deforestation to changes in radiative forcing compared to 1750, assuming a steady state for other fire emissions.

Bowman et al., Science, 2009
Different processes adding to the indirect particle climate effect

<table>
<thead>
<tr>
<th>Effects</th>
<th>Cloud type</th>
<th>Description</th>
<th>Forcing</th>
</tr>
</thead>
<tbody>
<tr>
<td>First indirect aerosol effect (Twomey effect)</td>
<td>All clouds</td>
<td>The more numerous smaller cloud particles reflect more solar radiation</td>
<td>- 0.5 to - 1.9</td>
</tr>
<tr>
<td>Second indirect aerosol effect (Albrecht affect)</td>
<td>All clouds</td>
<td>Smaller cloud particles decrease the precipitation efficiency, thereby prolonging cloud lifetime</td>
<td>- 0.3 to - 1</td>
</tr>
<tr>
<td>Semi-direct effect</td>
<td>All clouds</td>
<td>Absorption of solar radiation by soot may cause evaporation of cloud particles</td>
<td>+ 0.1 to - 0.5</td>
</tr>
<tr>
<td>Glaciation indirect effect</td>
<td>Mixed ice and liquid water clouds</td>
<td>More ice nuclei increase the precipitation efficiency</td>
<td>0.2 to 1</td>
</tr>
<tr>
<td>Thermodynamic effect</td>
<td>Mixed ice and liquid water clouds</td>
<td>Smaller cloud droplets delay the onset of freezing</td>
<td>Uncertain</td>
</tr>
<tr>
<td>Riming indirect effect</td>
<td>Mixed ice and liquid water clouds</td>
<td>Smaller cloud droplets decrease the riming efficiency</td>
<td>Uncertain</td>
</tr>
</tbody>
</table>
Hydrological cycle critical for Amazonia. Variety of cloud structure caused by different CCN amounts and other cloud dynamic issues.
Large scale low cloud suppression by biomass burning aerosols

Terra and Aqua satellite images of the east Amazon basin, 11 August 2002. (A) The clouds (Terra, 10:00 local time) are beginning to form. (B) The clouds (Aqua, 13:00 local time) are fully developed and cover the whole Amazon forest except for the smoke area. The boundary between forest and Cerrado region is marked in white on both images, and the seashore is marked in green. (From Ilan et al., Science March 2004)
Suppression of low cloud formation by aerosols in Amazonia

Cloud fraction as function of aerosol optical depth (OD).
On average, the cloud fraction decreases to less than 1/8 of the cloud fraction in clean conditions when OD = 1.  
(Koren and Kaufman, 2003)
Left – cloud top pressure \((P)\) vs. AOD. Lower \(P\) may indicate taller convective clouds.

Right – cloud fraction vs. AOD.

The upper row is for all data and the lower row is for data restricted to cloud fraction less than half.

Koren et al., Science 2008
Regional analyses of the AERONET data for the effect of aerosols on cloud cover. $\Delta f_{ci}/\Delta \ln \tau$ was plotted as a function of $\tau_{abs}$. 

Kaufman et al., Science 2006

Reduction in cloud cover depends on the absorption optical thickness.
Major Rainfall Shifts during the last 50 Years
Observed Trends in Summer Rainfall: 1950 to 2002

Chung and Ramanathan 2006

The Sahelian Drought
The Weakening Indian Monsoon
N-S Shift in Asian rainfall
Interactions of urban air pollution with pristine forest emissions
Fig. 2: 3-D plot of the plume Flight #18 on 19 July 2001. After take off at the airport of Manaus the flight pattern was set up as a Lagrangian experiment with a series of stacked horizontal profiles (with 3-6 crosswind transects each) in the urban outflow at successive distances downwind of Manaus City (10, 40, 70 and 100 km). The flight altitude is colour-coded in blue (z-axis). Red lines indicate the VOC cartridge sample intervals within some of the plume transects. The grey line is the XY-projection as in Fig. 1.
Interactions of urban air pollution with pristine forest emissions
The colour code of NO was selected to resolve values of 0-500 ppt, while the dark red colour in the vicinity of Manaus City includes values up to 10 ppb of NO.
Thanks for the attention !!!
“Dimming” and “brightening”: large scale changes in surface radiation

1950 to 1980

Change in AOD between 1950 and 1980

\[ \text{'Global' dimming} = -1.2 \text{Wm}^{-2} \]

1980 to 2000

Change in clear-sky downwards surface SW between 1950 and 1980

\[ \text{'Europe' brightening} = 5-10 \text{Wm}^{-2} \]

Wild JGR 2008.
Simulated linear trends in surface solar radiation under cloud-free conditions for the (a) “global dimming” period 1950 – 1990 and (b) “brightening” period 1990 – 2002. Simulations ECHAM5 HAM [Stier et al., 2005, 2006]. Units are Wm$^{-2}$yr$^{-1}$

Observed temperature anomalies over global land surfaces during the 20th century. There is indication for a suppression of greenhouse-induced warming through “global dimming” between the 1950s and 1980s, and an enhancement through “brightening” between the 1920s and 1940s as well as from the 1980s onward. Anomalies with respect to the 20th century average. Wild JGR 2008.
Modeled global changes in surface ozone

Radiative forcing of tropospheric ozone: $+0.35 \text{ (0.25-0.65) Wm}^{-2}$

Ozone important for OH, strong oxidant, damage to plants, health effects, etc.

CCN concentrations and AOD over the cleanest continental sites are similar to the cleanest marine sites

M. Andreae, ACP 2009
Is there any sign of significant trends that indicate increased diffuse fraction over the Amazon?

The trends in AOD are strong: trend $>0.1$/year

This will increase the diffuse fraction of radiation

Data from September (~max of biomass burning) from AERONET stations
Very high spatial and temporal variability in particle concentrations
Aerosol optical depth from 1999 to 2009 for 10 sites in Amazonia
Reduction in absorbed solar radiation at the surface by all anthropogenic aerosols (BC and non-BC) in ABCs.

The absorption of solar radiation by the atmosphere due to ABCs (Chung et al., 2005).
CO2 July 2009 with the Atmospheric Infrared Sounder instrument (AIRS) on NASA's Aqua satellite. The image shows large-scale patterns of carbon dioxide concentrations that are transported around Earth by the general circulation of the atmosphere. A belt of enhanced carbon dioxide girdles the globe in the southern hemisphere, following the zonal flow of the southern hemisphere mid-latitude jet stream. This belt of carbon dioxide is fed by biogenesis activity in South America (carbon dioxide is released into the atmosphere through the respiration and decomposition of vegetation), forest fires in both South America and Central Africa.
Complicated case: CO2, isoprene and implications for future O3

- Leaf isoprene, normalised vs CO2 (ppm)
- Global isoprene vs time (1900-2100)
- Map showing global distribution
Estimated Total Reactive Nitrogen Deposition from the Atmosphere (Wet and Dry) in 1860, Early 1990s, and Projected for 2050 (milligrams of nitrogen per m²/year)